Effects of Atmospheric Contaminants under Hyperbaric Conditions with Particular Reference to Vision

by

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SUMMARY PAGE

The Problem:

To catalog the effects of atmospheric contaminants under pressure, particularly on vision.

The Findings:

Few studies have been carried out to examine the effects of atmospheric contaminants on vision at any pressure. Those dealing with the effects of oxygen, nitrogen carbon monoxide and dioxide, ozone, organic vapors, trace metals, and a common refrigerant are presented.

Application:

The results of these studies are of interest to divers and to those concerned with the problems of submarine rescue.

Administrative Information

This report was submitted for review on 9 July 1986. It was approved for publication as an NSMRL Memorandum Report on 13 August 1986.

Abstract

A literature search has been carried out for studies investigating the effects, particularly on vision, of atmospheric contaminants under pressure. Little is known of the effects on vision of most contaminants under any pressure. What is known of the effects of oxygen, nitrogen, carbon dioxide and monoxide, ozone, organic vapors, trace metals, and a refrigerant are presented.

Effects of Atmospheric Contaminants under Hyperbaric Conditions

Research at the Naval Submarine Medical Research Laboratory is primarily concerned with the health and performance of submariners. Although the atmospheric pressure in submarines is kept at that of sea-level, there are nevertheless several reasons for interest in the effects of hyperbaric conditions.

One is that the submarine air-banks are used to charge the Scuba tanks of divers who are deployed from the submarines. The air in the tanks is of course under high pressure.

A second reason is that consideration is now being given to reducing the hazard of fire on submarines by reducing the concentration of oxygen in the submarine atmosphere. To offset the reduction in the percentage of oxygen, it may be desirable to increase the partial pressure of oxygen by increasing the atmospheric pressure.

A third reason has to do with the problems involved in submarine rescue. If a submarine becomes disabled and takes on water, the air in a partially flooded compartment is compressed to the pressure of the surrounding sea. The surviving crewmen would then be awaiting rescue under hyperbaric conditions. A disabled submarine which has taken on water will, of course, have suffered some damage, and it is reasonable to assume that there will have been an appreciable increase in the concentration of contaminants in the atmosphere. This may result from the malfuncton of the atmospheric scrubbers, from the rupture of oil lines, or from other sorts of damage. The effects on the crew of these contaminants under pressure is clearly of interest, since it appears possible that most are mutagens or carcinogens (Umstead, 1970; Hazard, 1973).

This survey is primarily concerned with the effects of common atmospheric contaminants under pressure on vision. It has sometimes been argued that visual parameters are the most sensitive to physiological insult and that visual deficits often appear before any other symptoms. Anger (1984) has tabulated the types of neurotoxic effects reported after exposure to a wide variety of chemicals. Of the 70 symptoms reported, the most widely reported was stupor or narcosis. This was reported with 28 of the toxins in his survey. The next most widely reported effect was cholinesterase inhibition-- 26 times. The third effect was some sort of pathology of vision, reported 21 times. Since a visual defect can probably be measured more objectively than narcosis, it seems to be a good measure to focus on.

On the other hand, the retina is an extension of the brain, and it may be that the central nervous system is given the most protection and may be among the last to be affected. Luria and McKay (1972) reported an experiment in which subjects were to breathe low concentrations of carbon monoxide. The air mixtures, however, were accidentally contaminated with such substances as nitrous oxide and freon-- apparently not an uncommon occurrence (Rownan and Susbielle, 1985). Three of the four subjects experienced very severe respiratory distress; indeed, two of the subjects were on the verge of fainting by the end of the three hour exposure. Yet, only very small changes were found in such visual measures as scotopic sensitivity, perimetry, foveal increment thresholds, and visually evoked potentials.

Submarine atmospheres typically contain a large number of contaminants (Piatt and Ramskill, 1970; Johnson, 1962; Bondi et al, 1983; USN, 1970; Knight, et al, 1985). As many as 300 have been identified. Among them are carbon-dioxide, carbon-monoxide, hydrogen, refrigerants, aliphatic and aromatic hydrocarbons, ozone, and metal ions (Knight et al., 1985). The degree to which they will vaporize varies greatly (Popendorf, 1984), and most of them, of course, are present in very small quantities. The effects of only a few of them have been studied even at normal atmospheric pressure; there is little knowledge of what their effects will be under pressure. Will pressure potentiate any toxic effects that they have? Or, since hyperbaric oxygen (HBO) is now coming into wide use as a therapeutic agent (Davis, 1985), will the presence of high oxygen tension ameliorate toxic effects?

The answers are not obvious, for it has been noted many times that the action of a substance under pressure is not predictable from its effects under normobaric conditions (Thomas and Walsh, 1978; Jacobsen, 1983). Moreover, the effects of one substance may be altered by the presence of other substances, which is, of course, the basis of therapeutics. Most frustrating for practical purposes are the findings that a substance may be beneficial at one pressure and toxic at another pressure (Gerschman et al, 1953). On the other hand, the effects of many drugs appear to be the same under normal and high pressure (Small, 1970).

Fifteen years ago, Umstead (1970) stated flatly that "The physiological effects of organic trace contaminants under pressure are not known (p. 3-1), and Hazard (1973) made the same point shortly afterwards. In fact, there does not appear to be much information on the subject even today. It is, of course, impossible to review the effects of 300 chemical agents. Moreover, it should be noted that some substances, not usually thought of as toxic, become so in high concentrations or under pressure. They must also be considered. Among them are the main constituents of air, oxygen and nitrogen. Only a few of the most prevalent or toxic substances will be considered in this review. Among them are oxygen, nitrogen, carbon-dioxide and carbon-monoxide, ozone, freon, the trace metals cadmium and zinc, and organic vapors in general.

OXYGEN

When one speaks of toxic substances under pressure, one must begin with oxygen itself. It is well known that excessive oxygen is toxic (Lambertsen, 1965; Haugaard, 1968; Wolfe and Devries, 1975; Simon and Torbati, 1982). Behnke et al. (1934; 1935) reported many years ago that visual symptoms become prominent under exposure to HBO. Four men were exposed to oxygen at 3 ATA for 4 hours. Although they tolerated the exposure well for the first three hours, there was a 25 percent impairment in visual acuity. During the fourth hour, there was a dramatic reduction in visual acuity and a loss of ability to recognize red and green. Several investigators have reported a dilation of pupil diameter (Behnke, et al, 1934; 1935) or degraded reactions by the pupil to light (Beehler et al, 1963), which may well be a factor in the reduced visual acuity. There have been several reports of dramatic constrictions in the visual field after three hours of exposure to 3 ATA (Behnke, et al 1935; Donald, 1947; Rosenberg et al, 1966; Clark et al, 1934). Most interesting are the reports that HBO induces myopia (Anderson and Farmer, 1978; Lyne, 1978; Fischer et al, 1983). In addition, HBO has been found to result in cataracts, at least for older people (Nichols et al, 1972; Anderson and Farmer, 1978; Schocket et al, 1972), and also to attenuate the ERG (Bridges, 1966; Criswick and Harris, 1967; Watanabe et al, 1970; 1972; Shaw and Leon, 1970; Noell, 1962). It goes without saying that there are wide individual differences in the time of onset and the severity of these effects (Kent, 1966; Clark and Lambertsen, 1971; Nichols, et al, 1972).

TRACE METALS

Yet the toxic effects of oxygen can be markedly attenuated by other contaminants, such as carbon dioxide, metal ions, chelating agents, and sulfhydril compounds (Haugaard, 1968). Cobalt, manganese, and nickel have been found to protect against oxygen toxicity (Haugaard, 1968). In addition, they exhibit an antagonism to other trace metals that have toxic effects.

The trace metals most often found in submarines are cadmium and zinc. The main source of the latter is galvanized metal which gives off zinc-oxide when heated. The main source of cadmium is cigarette smoking (Moreau et al 1983; Mussalo-Rauhamaa et al 1986), but it is also used in low friction bearings which fume when heated, and it is found in many types of silver solder (U.S. Navy, 1970). The first symptoms of cadmium poisoning are reported to be fatigue, peripheral neuropatny, and loss of smell (Weiss, 1983), after which serious pulmonary disorders are said to develop. Thatcher et al (1932) have also found that exposure to cadmium is correlated with reduced scores on I.Q. tests. Stellern et al (1983) found a highly significant negative correlation between hair-cadmium levels and performance on the Bender Gestalt test, a visual-motor test. This, of course, indicates deterioration in fine motor reactions rather than visual performance. Other investigators have reported impairments in visual development resulting from exposure to cadmium (Byers and Lord, 1943; Pnil et al 1979).

Zinc poisoning also results in such symptoms as extreme fatigue, thirst, shivering, and perhaps fever. Khosla et al (1983) reported that intraperitoneal administration of zinc-sulfate resulted in a decrease in the "a" wave of the electroretinogram (ERG) after four weeks and in the total ERG after 3 weeks. Radomski and Wood (1970) found that intraperitoneal injections of aqueous solutions of zinc salt prevented the development of lung edema in rats exposed to hyperbaric oxygen. This does not mean that the presence of zinc ions in the atmosphere will exert the same effect, but it does suggest that the presence of trace metals may not always be harmful. It is not surprising, of course, that these substances may be beneficial at one concentration and toxic at another. But one of the trace metals, cobalt, has been reported to increase the survival time of mice exposed to 1 ATA of HBO but have no influence or detrimental effect at higher pressures (Gerschman et al, 1958).

NITROGEN

The other primary component of air, nitrogen, also has under pressure a well-known detrimental effect on performance which is called "nitrogen narcosis" (Bennett, 1982). And the combined effects of oxygen and nitrogen under pressure may be greater than the arithmetic sum of the effects of either gas alone (Thomas, 1974). It seems to be generally agreed, however, that the behavioral changes under nitrogen narcosis are not mirrored by any sensory changes. Visual functions measured without any motor or cognitive aspects do not show any particular decrements (Biersner, 1972; Schellart, 1976; Fowler and Granger, 1981), and this is also true for nitrous oxide (Biersner 1972). Visually evoked potentials, however, do show a marked decrement in amplitude under high pressures of nitrogen (Kinney et al, 1972).

CARBON DIOXIDE

The most common pollutant in closed air systems is probably carbon-dioxide (CO_2) which comes simply from breathing. There has, accordingly, been an enormous amount of work on its physiological and psychological effects, but again relatively little of it under hyperbaric conditions. Bloom (1970) reported that there were some indications that CO_2 was retained under pressure. Thus we would expect the effects of CO_2 to be increased under pressure. Schaefer (1974) investigated this in more detail and found that it is possible to produce marked CO_2 intoxication in most subjects without the warning signs of severe respiratory dyspnea. Moreover, Schaefer (1974) and Hesser et al (1971) both reported that raising CO_2 and N_2 (or N_2O) pressures simultaneously produced greater changes than were produced by either gas alone. The former did no visual testing, but the latter found greater changes in two-hand tracking and on the Stroop Test than was induced by either gas alone. Thomas (1971) found an interaction effect on the operant performance of rats.

Weitzman et al (1969) found that exposure to 3.0% CO_2 for 15 hours a day at 1 ATA impaired night vision and sensitivity to green.

On the other hand, high doses of CO_2 inhibit the convulsions resulting from oxygen toxicity, probably because of the narcotic properties of CO_2 at high concentrations (Marshall and Lambertsen, 1961).

CARBON MONOXIDE

A discussion of CO_2 at once suggests the topic of carbon-monoxide (CO). As befits a very dangerous substance, there has been considerable study of its effects both at normal and increased pressures. As is well known, the presence of CO is dangerous, because hemoglobin has a far greater affinity for it than for oxygen. As the amount of CO in the bloodstream increases, the individual exhibits a well known series of symptoms and behavioral deficits (Purser and Berrill, 1983). Halperin et al (1949; 1959) reported that relatively small levels of carboxyhaemoglobin (COHb) resulted in a rise in the absolute threshold of vision. However, subsequent investigations (Luria and McKay, 1972, 1979; Luria, 1977) in which subjects were exposed at 1 ATA to either 200 ppm for as much as 3 hours or 500 ppm for one hour showed virtually no effects on a wide variety of visual processes, including scotopic sensitivity, foveal increment thresholds, perimetry, stereoacuity, eye-movements, visual masking, and evoked potentials. And recently, Knight et al (1986) failed to find any visual deficits resulting from exposure to low concentrations of oxygen.

Would these effects be greater under pressure? Several investigators (Rodkey, et al, 1969, 1971; Rose, et al, 1970; Small and Friess, 1975) have found that increased pressure up to 21 ATA does not change the affinity of hemoglobin for CO. Neither the lethal concentration of CO nor the blood COHb concentrations varied with exposure pressure (Rose et al, 1970). These results suggest that increased pressure would not increase the effects of CO which occur at 1 ATA. Indeed, in view of the fact that hyperbaric oxygen is the treatment of choice for CO poisoning (Litavrin, 1983; Ziser et al, 1984), it seems even more unlikely that the effects of CO would be exacerbated under pressure.

OZONE

Ozone is commonly produced by discharges from electrical equipment, mostly from the two types of electrostatic precipitators on submarines. "Ozone is one of the most toxic and ubiquitous air pollutants" (Menzel, 1984). Kelly (1965) published the first report of acute human intoxication from ozone. Its effects are probably not widely known, because its odor is objectionable when the concentration reaches .10 ppm, considerably below the concentration of 0.5 to 1.0 needed to produce any symptoms. Respiratory and biochemical effects have been most studied, as well as susceptibility to infection, chromosomal effects, and hematology. There have been few cardiovascular or sensory studies. Lagerwerff (1963) has reported decreased scotopic acuity after exposure to 0.2-0.5 ppm for three hours. But he also found an increase in peripheral vision, and further study would be desirable. No studies have been done under pressure.

ORGANIC VAPORS

The toxicity of the vapors of the hydrocarbon compounds is well known (Clark and Tinston, 1982), and the synergistic effects of combinations of such compounds has been reported (Kluwe et al, 1982). There are a large number of aromatic and aliphatic hydrocarbons carried on submarines. They include solvents, diesel fuel, lubricating oils, cooking oils, sealers, tobacco smoke, and many others.

Studies of the toxic effects of hydrocarbons have typically investigated the pulmonary or cardiac systems (e.g., Clark and Tinston, 1982; Reinhardt et al., 1971) or ability to function (Gaume, et al., 1971). Little is apparently known about the effects on vision at any pressure.

REFRIGERANTS

A common refrigerant--although not one of those used on submarines apparently-- is bromotrifluoromethane. Its effects on EKG, blood gases, and visually evoked potentials have been studied at the pressure of 165 FSW (Greenbaum et al., 1972). After 5 minutes of exposure, there were only small reductions in the amplitude and latency of the VERs, and small changes in the other variables studied. In the lght of these results, it is unlikely that any visual effects would have been found.

If this refrigerant is similar in such physiological characteristics as lipid solubility to that of the refrigerants on submarines, then we would expect similar results.

CONCLUSION

Our knowledge of the effects on vision of these various contaminants at normal atmospheric pressure is surprisingly scant, and studies of their effects under pressure are close to being nonexistent. There is clearly opportunity for research whose results would be of great interest.

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A literature search has been carried out for studies investigating the effects, particularly on vision, of atmospheric contaminants under pressure. Little is known of the effects on vision of most continimants under any pressure. What is known of the effects of oxygen, nitrogen, carbon dioxide and monoxide, ozone, organic vapors, trace metals and a refrigerant are presented.